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A Continuum of Students' Science Identity Strengths

*(**Running head:** Students' Science Identity Strengths)*

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Abstract

This article describes a unique instrument will monitor the strength of secondary students' science identities. Teachers spontaneously collect observational data in situ to identify, tentatively and privately, where a student currently belongs on a continuum partitioned into six ordinal categories. The authors categorized a representative group of Grade 9 students who had originally volunteered to participate in an earlier research project defined by the research question: What are the thoughts that a group of ninth-grade students have about Nature? The present article's research question is very different: Where would these students tentatively fit on a teacher-produced continuum of science identity strengths? The authors' categorization of the students illustrates how teachers should create their own criteria. Thus, the age of the students' reported interview data is moot. To avoid publicly labelling students and to promote equity, the continuum should not be used for streaming students, nor should students learn of its content. The spontaneous in situ data-collecting process itself promises to improve the communication between a teacher and their students who possess weaker science identities. Yet they tend to possess stronger humanities identities or everyday-context identities.

Keywords:
humanistic, secondary school science, science identities.

Introduction

Low achievement in high school mathematics, especially algebra, frustrates both science teachers and many students, and it negatively impacts their achievement in the sciences (Schmalz, 1991). "Students have called this [algebra] math course 'torture,'" according to entrepreneur Bill Gates (2021, website quote).

With respect to this problem, Bang and Medin (2010) insightfully recognized the cultural nature of both mathematics and science: "Although the construct of culture is problematic, people nevertheless 'live culturally' … [by way of] a wide repertoire of sense-making practices that people participate in, particularly in everyday contexts" (p. 1014). Thus, peoples' sense-making practices, such as doing science and mathematics, refers to people's actions. Bang and Medin's perspective turn science and mathematics into a verb, so to speak. Simply put, school subjects teach different sense-making processes (i.e., an action) associated with a particular worldview (Author 2, 1991) that embraces a certain set of values.

The subliminal culture-based problems that frustrate many students in their science classes arise from the fact that their values supporting their everyday sense-making processes differ from those of mathematicians or scientists, *to varying degrees*. Ernest (2018) articulated this clash of values by drawing upon the notable Carol Gilligan's (1982) axiological research that identified predominant clusters of values that tend to be held by various groups of people, to varying degrees. Two of her clusters are relevant here: separation versus connection value clusters (cited in Ernest, 2018):

> The *separated* position valorises rules, abstraction, objectification, impersonality, unfeelingness, dispassionate reason and analysis, and tends to be atomistic and thing-centred in focus. The *connected* position is based on and valorises relationships, connections, empathy, caring, feelings and intuition, and tends to be holistic and human-centred in its concerns. (pp. 194–195).

These two clusters, separated and connected, relate to Snow's (1956) classic dichotomy "The Two Cultures," the sciences and humanities, respectively. Snow advised each academic community to build bridges between their two academic domains.

We recognize these dichotomies, and others like STEM vs non-STEM, as a cultural epistemic habit that risks oversimplifying a deeper understanding that the expression "degrees in differences" can entail. We apply this recognition, for example, by treating Gilligan's insightful work as a *disjunctive signpost inviting us into a topic, rather than mimicking Plato and/or Aristotle by telling us the truth established by a dichotomy.* An Ipsos (2005) poll concerning peoples' favorite high school subjects found that adults (N = 1,000) between the ages of 20 and 39, favored their humanities subjects 3.5 times greater than their science subjects (52% versus 15%, ± 3, respectively). Although polls

reveals that a large *majority* (3.5 to 1) of former students of high school science prefer their science content taught to them in a humanistic or everyday context so they can feel a *connection* to how science is used in their mainstream culture (-& Author 1, 2022). Two quite different research projects conducted with high school students—the U.S. Office of Technology Assessment (OTA) (Frederick, 1991) and the National Bureau of Economic Research (NBER) (Card & Payne, 2017)—agreed that an 85% majority of high school graduates is comprised of the non-STEM students (see section Quantitative Descriptions).

This large majority tends to experience a clash of values to varying degrees, between, on the one hand, their values associated with the lens through which they tend to view their everyday world; and on the other hand, the values associated with the lens through which scientists and science teachers tend to view their world (Ernest, 2018). However, a notable *minority* (15%) of high school graduates do not feel this way. Instead, they want a pre-professional STEM preparation for college or university programs according to the "Next Generation Science Standards" (Zucker, 2021, p. 8).

To avoid labelling this wide diversity of science students with simplistic dichotomies (e.g., non-STEM vs STEM), Author 1 (2021b) developed a heuristic, six-category, mathematics identity continuum that goes from one extreme, the "math-phobic," to the opposite extreme, the "math-oriented" (p. 480). A student's degree of disharmony would be indicated by how far away a student's categorization was from the math-oriented category.

Strong disharmony helps explain the low student achievement problem that frustrates science teachers and most students alike (Schmaltz, 1991). It is a different type of explanation than the familiar content (i.e., curriculum) versus process (i.e., pedagogy) perspective. It adds a third dimension: the cultural *context* associated with the curriculum and pedagogy. The context most important to most adolescents is their self-identities in general (e.g., Barton et al., 2013; Brickhouse, 2001; Darragh & Radovic, 2018), but also their science identities specifically (e.g., Aschbacher et al., 2010; Avraamidou & Schwartz, 2021; Brickhouse, 2007).

Understandably, teachers measure their own teaching success by their students' marks. The science identity continuum is another measure of success that provides professional development feedback to teachers, in which they have a role in deciding what science identity means to them. In other words, the continuum is not another standardized instrument. Its force resides in opening one's eyes to a dimension of learning that has personal meaning to students: science identities, described in the the next section.

A science continuum reflects the *diversity* of students' self-identities that have such a large influence on student learning in the sciences and mathematics (e.g., Chow-Garcia et al., 2022; Krogh & Andersen, 2013; Vincent-Ruz & Schunn, 2018). This article's science identity continuum offers educators a way to focus on, and monitor changes in, the strengths of students' science identities. Schools could innovatively plan the content, contexts, and pedagogies for their secondary science programs. For example, making connections between Snow's Two Cultures, a school could respond to the sense-making practices of students who experience their everyday world through the lens of Indigenous worldviews or the humanities, to various degrees; as well as making connections to the sense-making practices of students looking forward to embracing a science-related future.

Accordingly, this article has two purposes: (a) to draw on authentic, qualitative, and empirical data to suggest in detail the meanings of a science continuum's six ordinal categories; and (b) to make the continuum serve as a self-directed professional development project to improve students' science identities. The continuum is not a standardized one-size-fits-all-teachers type of instrument.

Science Identities

The construct science identity has received considerable attention in the science and mathematics education research communities, which have articulated both its great importance to student learning and its complexity that evades a standard definition. But educators agree on the fact that students construct their science identities which are open to modification (Aschbacher et al., 2010; Avraamidou & Schwartz, 2021; Barton et al., 2013; Brickhouse, 2007; Chen & Wei, 2022) and are closely associated with a person's sense-making processes.

The educational goal for using the science identity continuum is *to enrich* the repertoire of students' sense-making processes, but not at the expense of reducing their humanistic, or every day, or Indigenous sense-making practices.

The issues related to school-subject identities are closely shared by mathematics and science educators. The renowned mathematician, Reuben Hersh (1997), characterized mathematics this way: "We take it as self-evident that mathematics [and science] must be understood as a human activity, a social phenomenon, part of human culture, historically evolved, and intelligible only in a social context" (Hersh, 1997, as quoted by Skovsmose & Greer, 2012, p. 379). Contrary to stances such as mathematical Platonism and scientific positivism, mathematics and science are fundamentally human endeavors (Author 1, 2006, 2007, 2021; Author 2, 1993; Ernest, 1991; Saskatchewan Mathematics Curriculum, 2008; Sriraman, 2017; Zeyer & Kyburz-Graber, 2021), although very useful abstract subject matter can be extracted from their cultural sense-making practices.

The degree to which a student identifies with science's cultural features, the stronger the student's science identity becomes (Aschbacher et al., 2010; Darragh & Radovic, 2018; Ishimaru et al., 2015; Nasir. 2002). This occurs in at least three general ways: what they believe, what they value, and what they want to become. Researchers want "to understand what invites diverse young people to appreciate, to desire to learn, and to develop a sense of themselves as someone who [understands or] does science" (Aschbacher et al., 2010, p. 565). The greater a student becomes

emotionally engaged in a scientific activity, topic, or discussion, the stronger their science identity likely becomes.

More specifically, achievement in science tends to increase for many different reasons described by Ruef (2020): To be successful in [science] classes, students must negotiate and navigate the normative identity of the class—what counts as being "good at [science]." Within the constraints of normative identity, students must also negotiate a personal doer-of-[science] identity: who they are within the context of this particular [science] class. (p. 22)

Vincent-Ruz and Schunn's (2018) research on "persistency of minoritized populations within science trajectories has often highlighted identity as particularly important" (p. 1). For example, Aschbacher et al. (2010) wondered "why so many young people initially interested in science eventually choose not to continue learning science or pursuing careers involving science" (p. 565), specifically "science, engineering or medicine (SEM)" (p. 564). Their 3-year, mixed methods, longitudinal study investigated "access, activity, achievement, and attitudes" of 33 Grade 10 students, purposefully selected with respect to their ethnic and economic diversity, and who indicated they were "very interested in one or more SEM college majors or careers" (p. 567).

At the study's completion, "Three groups emerged with distinct characteristics and trajectories (High Achieving Persisters, Low Achieving Persisters, and Lost Potentials)" (p. 567).

Students' stories about their school, family, and extracurricular lives underscored the significant role that communities of (science and non-science) practice, key socializers, and students' gender, ethnicity, and socioeconomic status played in the development or dissipation of their identities, participation, and career goals in science. …The researchers explained how various types of interactions with diverse key individuals and groups, as well as students' gender, ethnicity, and socioeconomic status, [affected these students'] development or dissipation of their science identities. (p. 578)

Brickhouse (2007) distinguished between the concepts of science identity and self-identity. She characterized a science identity this way: "From a social cognition perspective …learning [science] happens as individuals become particular kinds of people. Learning is the acquisition of discourses of *thinking, acting, valuing, interacting, feeling that makes you a particular kind of person* [e.g., a science person to some degree]" (p. 90, emphasis added). This definition of learning is an important characterization of the student diversity continuum. It guided our categorization of students. Brickhouse (2001) described students' *self-identities* in terms of: "Learning science can change students' self-identities by changing their ability to participate in the world" (p. 288). Consequently, self-identity is a broader concept, but it is closely related to the concept science identity—the focus of the student diversity continuum.

A Science Identity Continuum

The ordinal categories for the science identity continuum are: science-resistant, science-avoidance, science-disinterested, science-interested, science-curious, and science-oriented. These self-defining category names are quite vague and open to wide interpretation. The following self-assessment for students might be less ambiguous, though perhaps not by much:

science-resistant: I generally distrust science; or I can get terribly anxious or sometimes even sick over learning science, especially when preparing for, and writing tests.

science-avoidance: I avoid thinking about science in or out of school, as much as I can get away with ignoring it.

science-disinterested: Science is not interesting to me, but I can usually memorize my way to a pass mark or higher.

science-interested: Science is interesting to me most of the time, although other subjects can be more interesting.

science-curious: Science is cool; it makes me curious most of the time.

science-oriented: Science is the best; I look forward to doing challenging science problems and learning new ideas as preparation for a science-related career.

Establishing a much more detailed meaning for each category is the first purpose of this article. The details were derived empirically from a set of qualitative data reported by Author 2 et al., (1999) and Author 2 (2000). This derived set of data is Appendix A.

On the continuum, the distance between a student's location and their science teacher's location holds implications for students feeling somewhat alienated or more at home in a science class. The less the separation, the greater is the harmony between the science class and a student's everyday sense-making practices. Therefore, there is room for science teachers to better understand every day or the humanities sense-making processes. This becomes the pathway for teachers to improve their communication with students who possess those every day or humanistic processes.

Because the science continuum represents students' science identities specifically and their self-identities generally, these two topics are clarified here before constructing a more precise meaning for each category in the continuum.

Characterizing the Continuum's Categories

In the present study, the continuum's six categories will be illustrated by an analysed version of the interviews of Grade 9 students by Author 2 et al. (1999) during their qualitative, descriptive, case study research. Their study asked, "What concepts have scope and power in [students'] thinking about Nature? [It inquired into] the personal thoughts, or everyday thinking, about a question relevant to science, what is Nature?" (Author 2, 2000, p. 2). These researchers produced a detailed narrative for each student, reported in Author 2's (2000) book as Appendix A. In contrast, the purpose of the present study is to categorize these same students on the continuum that represents the full range of students' science identity strengths. The original detailed narratives of the students contained information beyond the scope of the present study. Consequently, those narratives were edited into "thumbnail

sketches" (see Appendix A in this article) that contained only information pertinent to the present study's research question.

Each author of this present article then independently judged a student's science identity strength (with respect to the continuum's six categories) by analyzing their thumbnail sketch. This judgment indirectly produced the *in-situ* criteria for the judgment by each author. They were revealed through self-reflection. Finally, their two sets of *in-situ* criteria-in-use were integrated (see Appendix B). Thus, each category of the continuum was characterized, based on authentic narrative data.

Can authenticity be achieved with only 16 participants? Appropriate sample sizes differ dramatically between quantitative and qualitative research. Both the original and present studies are qualitative. In Vasileiou et al.'s (2018) medical research report, they state: "It has previously been recommended that qualitative studies require a minimum sample size of at least 12 to reach data saturation. Therefore, a sample of 13 was deemed sufficient for the qualitative analysis and scale of this study" (on-line quote). In addition, this position was defended in a reference to Lincoln and Guba's (1985) classic book *Naturalistic Inquiry*, in which a sample size of 15 was offered as satisfactory. Sarfo et al. (2021) "suggested that between 10 and 20 knowledgeable participants are sufficient to uncover and understand the fundamental categories" (p. 61). They continued, "Since narrative inquiry seeks to learn more about the narrator's culture, historical experiences, *identity*, and lifestyle, the emphasis is not on large sample sizes" (p. 62, emphasis added).

Author 2 and (2020) warn, "the concept of generalization should not be applied to qualitative work." (p. 74). The student narratives in the present study, Appendix A, are not used in any quantitative way. "Once you have captured the possible range of opinions, to whatever level of detail you seek, there is little reason to continue interviewing more people. You have reached 'saturation'" (p. 76).

Because the authenticity of these student narratives is crucial to the quality of their re-analysis in the present study, the original study is summarized here with sufficient information to warrant its trustworthiness (Lincoln & Guba, 1985; Messick, 1989; Whittemore et al., 2000), in order to establish the authenticity of the detailed description of the continuum's six categories; keeping in mind the tentativeness of students' science identities.

The Original Study's Context and Research Setting

Author 2 et al. (1999) explored the "thoughts that a group of ninth-grade students have about Nature" (p. 542) as a way to find out to what extent do those understandings of nature privilege science concepts over concepts in other domains of knowledge. In other words, the researchers singled out two criteria of interest: "students who showed an interest in science and whose understanding of Nature involved science" (p. 549) (i.e., students who drew on their understanding of science content).

Are these 25-year-old interviews out of date today? This question is moot, due to how those old data are used in the article. Author 2 et al. (1999) explained: "the foundational perspective for their research… is that one must hear from science students about themselves to better understand how they make—or do not make—science meaningful" (p. 542). Thus, two key research questions were of interest: "What science concepts are used in student conceptualizations of Nature, and to what extent are they used" (p. 558)? For instance, if a student explicitly rejected science for whatever reason, they would belong tentatively to the "science-resistant" group. If they did not mention science at all, they would belong tentatively to the science-avoidance or science-disinterested group; and so on.

Author 2 et al. (1999) discovered that their participants tended to discuss "the natural world using concepts from religion, aesthetics, conservationism, and science" (p. 547). The purpose of the present project is much different in two distinct ways: (1) it addresses only the science category; and (2) it uses the old student interview data in such a different way that makes that age a moot point, because those data are replaced by teachers' collected data: (a) observing in situ their own students during a semester; (b) deciding continuously which category of science identity strength they tentatively seem to resemble; (c) identifying their own criterion used for each time they classify a student (perhaps agreeing with the authors' criteria or not); thus, developing their own criteria for their own students. Thus, in the end, the 25-year-old student interview data have disappeared; replaced by what a teacher observed and interpreted in their own classroom.

In other words, we interest teachers in conducting their own project, over several months. We point out the benefits to repeating what we did, in their own science classrooms to develop their own criteria for each category; simply put, *to establish* what "science identity strength" means to them.

The original study's participating school was a "semirural high school in the central desert region of Arizona" (Author 2 et al., 1999, p. 546). All Grade 9 students from four classrooms were invited to volunteer. From these volunteers, 16 students were chosen so that there was a balance by sex and science grade success. Their names are pseudonyms. The students who participated in the research were as a group typical of students found in this high school's ninth-grade science courses. …The students were from middle- to upper-middle-income homes. (p. 546). "Fourteen students were Anglo-American" (Author 2, 2000, p. 32). The other two were Anglo-American-Indian and Anglo-Japanese.

Author 2 et al. (1999) justified the limit of 16 participants on the basis of "code redundancy" (p. 546) established in previous research, and recently updated by Author 2 and (2020).

A Comparison of the Two Studies

"The acid test of whether science has influenced the way a person thinks is not a set of explicit questions about science. …Rather, it is whether science has become an authentic part of a person's everyday thinking" (Author 2 et al., 1999, p. 545); in other words, the degree to which science has become part of a student's repertoire of cultural sense-making practices. This is also an apt description for "students' science identity strengths. Both the original study and the proposed professional development activity for teachers follow a qualitative research methodology (Author 2, 2000, p. 19). Details of the interview protocols are found in Author 2 (2000, Appendix C).

Interview audiotapes were transcribed and then coded by software programs, from which elaborate concept maps were developed for each of the 16 students and their teachers. A student's first-person interpretive narrative was then composed in two parts: quotations from the transcriptions, and observations from the researchers' informal classroom observations and interviews with the students' science teachers. These were validity-checked by each interviewee. These first-person interpretive narratives led to the raw data for the present study, described in the next section.

In contrast to this qualitative study is Chen and Wei's (2022) meticulous quantitative approach to the "development and validation of an instrument to measure high school students' science identity in science learning" (p. 111), with its research question: "What is the empirical evidence for supporting the validity and reliability of students' scores from the science identity questionnaire?" (p. 112). The researchers adapted an established theoretical framework for science identities, comprised of (the quotes that follow are from p. 114): (a) "*Recognition* – by others to be a good science student," (b) "*Interest* – Desire/Curiosity to think about & understand science," (c) "*Performance* – Belief in ability to perform on required science tasks," and (d) "*Competence* – Belief in ability to understand science content." These four constituents became scales in their final science identity questionnaire. "These results [established for Macau, China, students] supported the idea that development of science identity is a complex and multidimensional process which requires all dimensions to be adequately nurtured and developed" (p. 122). Their 23-item questionnaire has "a 5-point Likert-type scale …strongly disagree to strongly agree" (p. 116).

Furthermore, "Results of data analysis indicated that this instrument has strong construct validity and reliability when used with junior and senior high school students" (Chen & Wei, 2022, p. 111). However, the authors neglected to mention a key implicit assumption: that the students ascribed the same meaning to statements in the questionnaire as did the scholarly adults who wrote them and/or who interpreted the results. Back in 1990, Lederman and O'Malley established the naivety of such an assumption: "Language is often used differently by students and researchers and this mismatch has almost certainly led to misinterpretations of students' perceptions [of questionnaire statements] in the past" (p. 237). The more formal vocabulary and syntax of researchers' compositions and edits will tend not to connect smoothly with many secondary school students' vocabulary and syntax. For example, in a questionnaire concerning the nature of science, Author 1 (1987) reported: "Almost 100% of the students believed that scientific knowledge is tentative, but their reasons varied widely and in contradictory ways: a reconstructionist view (about 45%), a cumulative view (roughly 20%) and an exclusively technological view (about 20%)" (p. 484). Validity is undercut by such ambiguities.

Chen and Wei (2022) seem to have developed their science identity questionnaire without the benefit of reading the {information deleted for anonymity}. It "investigated the degree of ambiguity harbored by four different response modes used to monitor students' beliefs" (p. 607). Those modes and their associated ambiguities were reported as follows (all quotes come from p. 607):

1. The conventional Likert-type response turned out to be the most ambiguous, and thus, "the most inaccurate, offering only a guess at student beliefs." Its ambiguity was much higher than 50%.
2. A paragraph written by a student turned out to contain "significant ambiguities in about 50% of the cases;"
3. A semi-structured interview was "the least ambiguous" of the four response modes, but was highly time consuming; and
4. Choosing among empirically developed multiple-choice items that were composed based on a plethora of student paragraphs about an STS topic. This response mode "reduced the ambiguity to the 20 % level."

Researchers had assumed that the same meaning of the instruments' wording was shared by: the students, the test developers, and the analyzers of students' responses. The assumption turned out to be significantly problematic.

Beyond the traditional constructs of validity (e.g., face, content, criterion, predictive, concurrent, and construct validity) is trustworthiness (Lincoln & Guba, 1985; Messick, 1989; Whittemore et al., 2001). "It does not dispense with methods for systematic study but locates them in the world of practice rather than in the abstract spaces of Venn diagrams or Latin Squares" (Mishler, 1990, p. 436). Of the four response modes described above, Chen and Wei's (2022) Likert-type of approach would likely produce the most ambiguity, covered over by the quantified outcomes which that approach produces.

Author 2 et al. (1999) took the time and effort to conduct semi-structured interviews, which can be expected to produce the least amount of ambiguity. In the present professional development activity for teachers interested in learning more about improving their communication with the diversity of their students, the teachers take the time and effort to note spontaneous instances of what a student says, acts, or completes; which leads to a tentative categorization in developing a student's science identity strength continuum over a period of time.

The present six-category science identity continuum draws on the outcomes of adults listening to student voices (i.e., their interviews), rather than students interpreting adult compositions (e.g., questionnaires). Neither methodology, qualitative or quantitative, can claim ubiquitous validity; it depends on the context. When the topic is personal, as students' science identities are, a qualitative methodology reflects the personal. We also use a quantitative methodology when the context requires mathematics' quantitative ideology (Ernest, 2016) (e.g., in the present article, see section Quantitative Descriptions).

Methods for Qualitatively Describing the Continuum's Categories

The continuum's ordinal categories convey some impressions of students' self-identities. Colloquially, students' self-identities can mean: who they are, where they have been, where they are going, who they want to become, and how they tend to be perceived by others. However, in the students' thumbnail sketches of their narratives (Appendix A), the focus is placed on their *science* identities. But some sketches may suggest other relevant information, such as the degree to which a student appears to embrace separated and/or connected value clusters (Gilligan, 1982).

In the present article, each student's narrative was reported in Author 2 (2000, Appendix A). It was reduced in size to coincide with our new research question concerning the detailed description of the continuum's categories by drawing on students' own words and actions. Simply put, the original "student narratives" became focused "thumbnail sketches." We *excluded from* the original student narratives expressions related to: students' personalities, family problems at home, their esthetic relationships with nature, their attention to stewardship isolated from any connection to science, and the degree to which they were religious unless it obviously affected their science identity. Only their perspectives that dealt directly or indirectly with their science identities are relevant to the continuum of science identity strengths. As stated above, Brickhouse (2007) characterized a science identity as, "An acquisition of discourses of thinking, acting, valuing, interacting, feeling that makes you a particular kind of person" (p. 90).

As mentioned previously, these thumbnail sketches served as the data to be analyzed in the process of assigning each student to one of the continuum's six categories. This analysis was accomplished independently by each co-author living in different countries. Then an email interchange ensued over the criteria they had brought to their judgements in matching a student with a category. The strategy was not to reach a consensus, but to make the most informed and independent judgement at the time; with an open mind to changing a categorization, given a more reasonable explanation for a classification by the other co-author. It was certainly acceptable to agree to disagree. This strategy coincides precisely with the continuum's anticipated professional development use by a classroom teacher, described below.

Tables 1 and 2 present the final classification results. The obvious disagreements provide the reader with some feedback concerning the continuum's natural susceptibility to different interpretations. In the future, if the continuum becomes a quantitative research variable, then it's reliability will need to be assessed in appropriate ways relevant to that future research study.

Table 1: Author 1's judgment of a cross-section of 16 Grade 9 students along the continuum of science identities

Science-Resistant	Science-Avoidance	Science-Disinterested	Science-Interested	Science-Curious	Science-Oriented
Art	Allen Holly Jackie Paula Simon	Betty Liz Sally Samantha	Ann* Bruce Patricia*	Howard	Alice Kevin
*More information needed for a more reliable categorization					

Table 2: Author 2's judgment of a cross-section of 16 Grade 9 students along the continuum of science identities.

Science-Resistant	Science-Avoidance	Science-Disinterested	Science-Interested	Science-Curious	Science-Oriented
Art	Allen Holly Jackie Paula Simon	Betty Sally	Ann Liz Patricia Samantha	Bruce Howard	Alice Kevin

The thumbnail narrative data in Appendix A of this present article are organized by the continuum's six categories, beginning at the science-oriented end of the continuum. These thumbnail sketches are organized according to the appearance of students in Table 1. The proportion of students' attention to religion, aesthetics, conservationism, and science are briefly summarized in the following subsection, "A Summary Analysis of These Thumbnail Sketches."

For the students listed in *each* category in Tables 1 and 2, it would likely be unreasonable to judge them hierarchically. Therefore, the students in the categories of Tables 1 and 2 are listed alphabetically. It was not unusual

to agonize between two adjacent categories when deciding on a few students' categorization. This is illustrated by the two co-authors' greatest disagreement: trying to distinguish between science-interested and science-disinterested students. More specifically, the first co-author suspects that he detected more instances of students playing Fatima's

However, on this ordinal scale, the disagreement was limited to vacillating between two adjacent categories only. The first author felt a lack of sufficient data in the thumbnail sketches to make a definitive categorization for Ann and Patricia.

The authors made their decisions based on Appendix A, in which the data are much more limited than a teacher's access to ongoing interactions with students, by which the teacher can mentally collect more relevant data as needed. A teacher's classroom set of students' personal science identity indicators (i.e., an 'Appendix A' for a class, developed over a year of pertinent entries) could be a rich resource of pedagogical feedback of personal interest to the teacher over a period of time.

A Summary Analysis of These Thumbnail Sketches

As Author 2 et al. (1999) pointed out, students tended to talk about nature from four perspectives: religious, aesthetics, conservationist, and scientific. The following summary analysis of the thumbnail sketches is organized according to these four perspectives. The thumbnail sketches accentuate the diversity among students in their motivations to engage in, or not to take on, science-identity work, to varying degrees.

1. Religious: Three different topics were identified: (a) Students successfully resolved or integrated their religious ideas with their thoughts about science: Kevin, Alice, Howard, Sally, Betty, Bruce, and Patricia. (b) Religion interfered with a science perspective: Paula, Simon, Samantha, Jackie, and Liz. (c) Religion was not mentioned: Holly, Art, and Allen.
2. Aesthetics: Three different aesthetic topics were also identified: (a) nature is beautiful: Ann, Samantha, Kevin, Alice, Bruce, Patricia, Betty, Liz, Simon, and Art; (b) nature is peaceful: Ann, Alice, and Samantha; (c) nature is relaxing: Samantha.
3. Conservationist: Patricia, Sally, Liz, Kevin, Allen, Samantha, Ann, and Bruce. Jackie related conservation to science when she wrote that science helps restore nature. The word "sustainable" or "sustainability" never appeared, perhaps indicating that the public's conversation has refocussed since the 1990s.
4. Scientific:

a. Specific scientific content examples were mentioned: Alice and Bruce
b. Science explains nature: Kevin, Bruce, and Sally
c. The statement, "*How* nature works and *why* it does so," contrasts science and religion, respectively: Alice, Kevin, Lia, Howard, and Patricia
d. "I'm more scientific than spiritual:" Betty
e. "Why study nature at all?" Paula
f. Science was neither mentioned nor alluded to: Holly, Sally, Ann, Art, and Allen (who stated, "most of nature is not knowable").

Rules. These rules are a set of strategies that make it appear as if in-depth learning and identity work (Brickhouse, 2007; Helme, 2021) has occurred; when only the most superficial and easily forgotten content had been memorized. Greater details are found below in the subsection "Fatima's Rules."

Unfortunately, three students were coping with dysfunctions at home that seriously impinged upon their attention paid to school work (Paula, Art, and Ann).

Six to eight students were categorized as showing an interest in science, and yet how very different their perspectives really are (Appendix A). Student diversity seems to be the strongest and most significant feature of many science classrooms.

The Original Study's Assertions

Of the original study's 15 conclusions composed as a series of assertions, only two provided further context for clarifying the continuum's categories. These included (Author 2 et al., 1999):

1. After 9 years of schooling, however, the level of science integration within everyday thinking remained low for many of these ninth graders. In their discussions of Nature, most volunteered little school knowledge of science. They were aware of school science topics such as the ozone layer, rain forests, and the Big Bang theory. Such topics were voluntarily mentioned but usually without elaboration even when asked.
2. Science grade success was not correlated with the concepts these ninth graders typically chose to use in a discussion about the natural world. The students with a grade of A in science had not necessarily grasped fundamental concepts about Nature and science. (p. 541)

This discrepancy in students' grades is explored next.

Playing Fatima's Rules

Patricia, Sally, Liz and Ann received a science grade of A, but were not in the top two categories of science identities. Author 2 et al. (1999) correctly attributed this to students "playing Fatima's Rules" (p. 557). The rules were named after a student, Fatima, who informed a science education researcher (Larson, 1995) how she and her friends passed their Year 11 chemistry course with a minimum of effort.

Besides test-wise memorizing, Fatima's Rules "include such coping or passive-resistance mechanisms as accommodation, ingratiation, evasiveness, and manipulation" (Author 1, 2011, p. 114). As a result, motivation to understand science meaningfully plummets (Nieswandt & Shanahan, 2008). "Therefore, playing Fatima's Rules contributes to declining interest and enrollment in science courses" (Author 1, 2011, p. 115). Some science-resistant and science-avoidance students may tend to play Fatima's Rules in response to what they perceive as an attempt by the teacher or school to assimilate them into the culture of science; and they will have none of it.

It could be noted in passing that the existence of Fatima's Rules also challenges the absolute validity of

student assessment in the context of a deep understanding of science; a view of which many teachers are aware. Therefore, the preoccupation of the public and politicians with the international PISA (Program for International Student Assessment) results would seem misguided. On statistically grounds, it is only valid for the top one-third of student achievers; and in general, the overall PISA project failed a validity audit (Author 1, 2021a).

Quantitative Descriptions

Tables 1 and 2 indicate the proportions of the Arizona Grade 9 students who expressed a positive or negative science identity, to various degrees. Table 1 has 37.5% positive, while Table 2 has 50% positive. Author 2 et al. (1999) mentioned, "The students who participated in the research were as a group typical of students found in this high school's ninth-grade science courses" (p. 546). The school's students were characterized as being "from middle- to upper-middle-income homes" (p. 546). Roughly speaking, how do they compare with large national research that address topics associated with students' science identity strengths? Two such studies measured two different aspects: student interest and student STEM readiness.

1. U.S. Office of Technology Assessment's (OTA) 16-year longitudinal study (Frederick, 1991), Table 3, began in 1977 with four million Grade 10 students, of whom 18% of this original sample expressed an "interest in natural science or engineering" postsecondary programs (p. 389) (*Interest*). This decreased to 15% near the end of Grade 12; and then to 9% of the original sample for those who actually enrolled in a college or university natural science or engineering program

Table 3: U.S. Office of Technology Assessment (OTA) pipeline data for students expressing an interest in future "natural science or engineering" programs (Frederick, 1991, p. 389).

Year:	1977	1977	1979	1980
Grade:	10	10	12	College Entry
Number of Students:	4,000,000	730,000	590,000	340,000
% Of initial sample:	100%	18%	15%	9%

2. The National Bureau of Economic Research (NBER) collected data on the percentage of Grade 12 graduates with sufficient STEM credentials (*STEM-readiness*) to attend a college or university, whether or not they actually enrolled in a postsecondary STEM program (Card & Payne, 2017). Their postsecondary enrolment was not recorded for this NBER "STEM-ready" (p. 2) group that comprised "14.5% females and 15.3% males" (p. 3) of Grade 12 graduates. Grouped together, this makes 14.9% of all graduates (15% rounded off). Because this is almost identical to the OTA's result, the 40 years difference between the two studies is not an issue. And not much seems to have changed in science education during the interval of 40 years that would increase STEM readiness.

The two somewhat different research projects result in two obviously different groups of students who comprise the full continuum:

A. A very large majority of 85%, 85% and 70% (OTA, NBER, PISA studies, respectively) who are not in the market for STEM-ready programs; but on which they are nevertheless currently assessed according to the "Next Generation Science Standards" (Marckwordt et al., 2022, p. 257; Zucker, 2021, p. 8); and
B. A notable minority of 15%, 15%, and 30% (OTA, NBER, PISA studies, respectively) who are interested in STEM and achieve well. They certainly deserve an excellent STEM-ready program in high school.

We suggest that the OTA and NBER studies relate much more closely to the actions of students and therefore to the continuum of students' science identities. The PISA proficiency results, which show a 15% increase over the OTA and NBER measures of interest and STEM readiness (respectively), may accounted for by a combination of: the proportion of students who rely on playing Fatima's rules, and the questionable validity of the PISA project.

The distribution is heavily skewed to the non-STEM side of the science identity continuum. This skewed distribution is an educationally significant finding. The Arizona school, located in a middle- to upper-middle-income neighborhood, was certainly above the U.S.A.'s norm, according to the data derived from Tables 1 and 2.

Conclusion

The present article proposed a continuum to serve as a teacher's private, self-directed, professional development project aimed at improving students' science identity strengths. Three critical loose ends need to be addressed for improving high school science: (a) curriculum reform for the majority group of students, and a continuation of the status quo curriculum for the minority group; (b) inequity traps, and (c) reasonable expectations by teachers.

Curriculum Reform for the Majority

Fundamentally, teachers cannot be blamed for students playing Fatima's Rules or having low science identities. Teachers are required to follow a high school curriculum dedicated to pre-professional training for the STEM professions studied in colleges and universities. This is a curriculum designed for the science-interested, science-curious and science-oriented—a 15% minority of high school graduates. Teachers are not only observing the proverbial tail wagging the dog, so to speak; they are participants in such an act, except for those teachers who have the ability and resources to connect with their students on a humanistic or everyday level, by going beyond the dictates of the curriculum and Common Core State Standards (Southerland & Settlage, 2022; Zucker, 2021).

In her article published in the *Journal of Humanistic Mathematics*, 16-year-old Rachel Steinig (2016) offered prescient advice to teachers: "[Assume that] everyone is intelligent in a different way. …If we know what's being done wrong, we can make it right" (p. 146). Perhaps the science identity continuum's categories could be renamed: highly humanistic, average humanistic, moderately humanistic, moderately scientific, average scientific, highly scientific. In addition, one should always keep in mind that a few students can be both average humanistic and highly scientific, among other such combinations.

Making it right for students in the 85% group requires a high school science program having a dual pathway of scientific literacies (science for living in a democracy, and science for pre-professional training in science-related fields), along with articulate and supportive parameters regarding students moving back and forth between pathways.

A. For the 85% majority, a scientific literacy curriculum aimed at everyday life, defined by the theme: the place of science in a democracy (not defined by documents advocating a program designed for the 15% should be for *every* student).
1. It is not a watered-down pre-professional training pathway, but it mimics an adult's stimulating and challenging everyday world; for example, from being a critical analyzer to a thoughtful decision maker, and then on to being a politically savvy citizen on science-related issues in peoples' lives.
2. Gaining in cultural capital by attaining higher marks is one main goal; while learning how science functions intellectually, socially, economically, and politically are supporting goals.
3. The ways and means of offering The-Place-of-Science-in-a-Democracy scientific literacy courses have been worked out by a cadre of science educators, researchers, and professional groups who have, over the past seven decades developed a rich array of curricular materials and pedagogical practices. These include the following domains of humanistic school science (Author 1, 2007; _____ & Author 1, 2022); for instance: history of science cases (HOSC) (Klopfer, 1969); science-technology-society (STS) (Author 1, 2006; Gallagher, 1971; Ziman, 1980); nature of science (NOS) (Duschl, 2022; Lederman, 2007); culture studies in science education (CSSE) (Avraamidou & Schwartz, 2021; Carlone et al., 2014); science-technology-society-environment (STSE) (Hurd, 1990; Pedretti, 2003); socio-scientific issues (SSI) (Zeidler & Sadler, 2011); science, engineering, and medicine (SEM) (Aschbacher et al., 2010); "science | environment | health" (S|E|H) (Zeyer & Kyburz-Graber, 2021); and civic science education (CSE) (Brickhouse, 2022; Levy et al., 2021). Duschl (2022) urges that "As we strive to negotiate challenges regarding Public Understanding Science …an appreciation for and understanding of past, current, and emergent histories of science remain paramount" (p. 488).

A. For the 15% minority, a scientific literacy curriculum aimed at the current pre-professional training theme will be slightly modified by:
1. "[adding] crosscutting concepts [that] are important because they provide a cohesive framework for making connections across disciplines" (Marckwordt et al., 2022, p. 257);
2. adopting a few International Baccalaureate topics or activities;
3. deleting content obsolete in today's digital age (Edwards, 2010), including what is no longer applicable to architecture, science, technology, engineering, mathematics, and medicine, etc.; for example, "I find that the vast majority of scientists, engineers, and actuaries only use Excel and eighth-grade-level mathematics" (p. 19); and
4. replacing that current irrelevant content with a few enrichment projects per course, related to humanistic science (see A.3. above); topics chosen individually or by small groups of collaborating learners.

A. Strict parameters include:
1. Provide Grade 9 science students with The Place of Science in a Democracy course theme, accompanied by specific elective examples of pre-professional training science. This gives all students encouragement to determine their comfort and interest levels with examples of a pre-professional training type of school science during Grade 9, so they can make a more informed choice of pathways for Grades 10-12. The "elective" nature of the material refers to students deciding (after the fact) whether their assessment on the pre-professional training material will be counted or not.
2. For Grades 10-12, ensure that student transfers between the two pathways are explicitly feasible and highly individualized. Promote an ease with which students can switch back and forth between the two pathways. This flexibility is a strict parameter.
3. "Each year, monitor the social, gender, and ancestral equity of students in each pathway, and then implement ways to augment equity" (Author 1, 2021a, p. 16; Avraamidou & Schwartz, 2021; Brickhouse, 2007) as needed.

The journal *Science Education* (2022) began its publication this year with a renewed purpose:

We are advocating for a renewed emphasis upon science education research that affords individuals and communities with the tools for productive scientific sensemaking. We view science when conducted equitably as offering knowledge to help make living on the Earth more sustainable and just. This shift in emphasis will require profound changes so science education can better guide all aspects of contemporary science teaching and learning.

Simply put, "we know what's being done wrong" (Steinig, 2016, p. 146) educationally; we know how to "make it right" (p. 146); but obviously, political priorities currently override the authentic needs of the large majority of high school students—this is an urgent agenda for high school science educators (Brickhouse, 2022; Duschl, 2022; Southerland & Settlage, 2022).

Inequity Traps to Avoid or Address

Helme (2021) wrote, "I have noticed that one of the discourses around the identity work of those labelled as low attaining, suggests a deficient positioning [i.e., an act of othering], that goes on to affect the teaching and learning experiences of students" (p. 3). When the difficulties of "the others" persist, "this was being positioned by teachers as due to lack of effort" (p. 3); rather than due to a clash of values between the struggling students and their teacher—perhaps the connected versus separated value clusters identified by Gilligan (1982), respectively. Helme (2021) demonstrated a Listening Guide technique (Gilligan et al., 2006) as one way a teacher might understand more effectively the science-disinterested, science-avoidance, and science-resistant students; many of whom, but not all, identify with the humanities, to varying degrees, as reflected in the Ipsos (2005) poll.

Some of the 16 Arizona students' choices of extra curricular activities indicated their humanities identity work, which teachers seldom consider or acknowledge. In such a scenario, a "try harder" directive from a teacher aimed at struggling students is easily received (misunderstood) as a directive to play Fatima's Rules (Tobin & McRobbie, 1997), or as an ill-conceived judgment: You *are not* intelligent (Helme, 2021).

The current social and political inequities in the culture of professional science should not be the elephant in the classroom. In the real world (Avraamidou & Schwartz, 2021): "who is seen as a 'science person' is highly gendered and racialized (Carlone & Johnson, 2007) and the construction of individual science identity is complicated by history and power dynamics The white male hegemonic context and deep-seated gender/race beliefs and barriers in STEM lead to individuals with minoritized identities in science (e.g., women and people of color) being challenged. (p. 341). This status quo aspect of Western science culture and to some extent, school science culture, can be challenged from time to time, pointing out positive examples of equity as they occur naturally in a science classroom.

Concerted encouragement should be a high priority for students who are historically marginalized in schools on the basis of their color, ethnicity, socio-economic-status, gender, or first language (e.g., Aschbacher et al. 2010; Barton et al., 2013; Brickhouse, 2001; Ruef, 2020).

Reasonable Expectations

In order for a student to move from having a science-avoidance identity to having a science-interested identity, that student's value system would somehow need to expand from a moderately "connected" cluster of values in a way that embraces a weak "separated" cluster of values (Gilligan, 1982). That may be an unreasonable expectation for many students. A more realistic aim would be a change of one science identity category every two years; emphasizing proficiency as a concern. By improving a student's science identity, we are modifying *who* a person is: perhaps what they believe, what they value, and what they want to become (Aschbacher, 2010).

The context of science instruction best begins where students are emotionally situated at the moment. In the example just above, the student was most likely originally contextualized within a humanities worldview. To have a two-category impact on a student would require a student to be personally engaged in relevant sense-making practices when learning the culture of science.

This issue has direct implications related to teaching humanistic school science (Author 1, 2007; _____ & Author 1, 2022; Hurd, 1990).

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APPENDIX A

Thumbnail Sketches of the 16 Students' Narratives

These thumbnail data of student narratives are associated with the continuum's six categories, beginning at the science-oriented end of the continuum. The original general description of the category introduces each category, followed by the thumbnail sketch for each student allocated to that category. The sequence of students within a category is alphabetical. Two types of narrative information are recorded for each student: quotations from their interview, and comments from the researchers who observed the 16 students in their classrooms. Each category ends with the student's assessment grade, if available at the time. These thumbnail sketches are organized according to the information in Table 1.

A. Science-Oriented

"Science is the best; I look forward to doing challenging science problems and learning new ideas, as preparation for a science-related career."

- *Alice*

1. "I want to be a scientist. Nature is very important to the world of science. Through science we understand many of the patterns in naturel food webs, weather patterns, how the solar system works, etc. We need to know more about Nature and we keep studying it to find out how things work and to discover ways that different things affect each other. While I am a Christian, I also believe that science has proved wrong, many of the things in the Bible. Science can explain how things work, but there are many why questions that science doesn't answer" (Author 2, 2000, pp. 127-128).
2. "Alice works hard for her 'A' grades. She would [like to] build a good life for herself based on a strong education and move out of her home as soon as she is able. Her goals are to attend 4 years of college and then to get a master's degree in either acting or biology related fields" (Author 2, 2000, p. 128). Assessment grade: B.

- *Kevin*

1. "I think Nature is very complex. There are unknown parts of Nature and they are confusing to me because there are no real laws controlling them. There is no order. ...I think that because Nature is so important to us, we need to work to learn more about it. We can learn about Nature through science. There is order to some things and we can base predictions on that. I want to be a scientist. Science raises many questions about Nature.

By trying to answer those questions, maybe we can learn to restore some of the changed, damaged parts of Nature. The ability to protect requires knowledge" (Author 2, 2000, p. 135).

2. "Kevin is a strong student. On a scale of 1-10, his teachers would rate him a 10. His study skills are well above average and he actively participates in classroom learning. Kevin expresses interest in the fields of architecture and designing and aerospace engineering." In Author 2 et al. (1999), the authors commented: "Kevin's interest in science had … everything to do with his environmentalist perspective" (p. 552). Assessment grade: A.

B. Science-Curious

"Science is cool; it makes me curious most of the time."

- *Howard*

1. "I think that Nature can be fully known because it is logical. As time goes on, we will understand more and more. Most things about Nature are somewhat orderly or have a pattern to them. Because of this, the study of science allows us to explain what is going on in Nature. The orderliness also lets us predict many things that are going to happen. Nature is very powerful and sometimes it seems chaotic, but that is mostly because our knowledge is incomplete and therefore our understanding is limited. I think that everything can be explained by science. I am a religious person but I also try to take things as they appear to me so I don't believe that everything in Nature has a spiritual side to it" (Author 2, 2000, pp. 129-130).

2. "Howard is clearly an intelligent young man, able to think his own thoughts and not embarrassed to discuss them and measure them against those of someone more knowledgeable than he. He also weighs what is said to him and does not automatically assume that what is taught is correct because it comes from an 'authority.' He intends to attend a state university and probably graduate school in the area of computer programming" (Author 2, 2000, 130-131). "Howard showed a strong inclination toward a scientific, utilitarian view of Nature. Howard made no reference to aesthetic or religious aspects of Nature. Rather, he appeared to focus on Nature as logical and orderly and fully amenable to scientific explication" (Author 2 et al., 1999, p. 549). Assessment grade: B-.

C. Science-Interested

"Science is interesting to me most of the time, although other subjects can be more interesting."

- *Ann*

1. "Nature is beautiful and pure because it is God's creation. Nature's resources are necessities but they are also limited. Nature is knowable, but the questions I ask about Nature make me think that Nature is sometimes very confusing. It is also changeable. Technology helps provide us with many wants" (Author 2, 2000, 133-134).

2. "Ann is a successful student. She has taken two science classes and plans to complete two or three more before graduating. She plans to go to either community college or a state university and would like, eventually, to enter a medical profession" (Author 2, 2000, p. 134). Assessment grade: A.

- *Bruce*

1. "Nature is complex, but it is orderly and knowable. Most of the natural world can be known through science and the theories that have been developed by science. Our knowledge is limited by hard questions, such as: Why does the Earth spin the way it does. What is gravity? Some things scientists know about are: weather patterns, El Niño, ozone depletion, and tectonic plate movements. The natural world is exploited because of us humans. As humans, we have personal and religious obligations to our world to take care of it." (Author 2, 2000, p. 140).

2. "He lacks maturity and critical thinking skills. Bruce wants to attend college and major in chemistry in order to become a dentist or a chef. He categorizes himself as being a very serious student although he slacks off a lot" (Author 2, 2000, p. 140). Assessment grade: B-

- *Patricia*

1. "God created the Natural World. It is very mysterious to me. The wonderment of the world increases knowledge through science but is limited due to its complexity. It's always changing. Some aspects of the natural world are understandable. Science and religion have distinct roles in our life teachings. Science teaches us how to conserve our resources and how to possibly restore them. Religion teaches us the caring attitudes required to be productive members of the natural world." (Author 2, 2000, p. 138).

2. "Patricia is an excellent student who has leadership skills and has an open-mind about new ideas. However, in the classroom she is easily distracted.… She plans to attend a state university and to eventually become a pediatrician" (Author 2, 2000, 138-139). (a) Assessment grade: A.

D. Science-Disinterested

"Science is not interesting to me, but I can usually memorize my way to a pass mark or higher."

- *Betty*

1. "God and Nature are intermingled in New Age spirituality. My understanding of Nature is more scientific and logical than spiritual, but there are some aspects of both attitudes in my thinking. Nature is complex and therefore mysterious. There are many questions that are still unanswered. We don't understand a lot of things in Nature because of its unpredictability. Things in Nature have a consciousness" (Author 2 et al., 1999, pp. 550-551).

2. "Although Betty began with orthodox comments about order in Nature and scientific understanding, she ended with startling comments from New Age mysticism, which she acknowledged was an influence in her home" (Author 2 et al., 1999, p. 551). Assessment grade: not reported.

- *Liz*

1. "The natural world is all the animals and . . .includes the environment and how they interact with it. It is the work of God. Its purpose is to help us live and enjoy things. The natural world is knowable by means of education through science and by learning through personal

experiences. Science tends to teach the how and what questions about the natural world and religion hints at the why questions somewhat. Because the natural world is knowable, it allows us to restore our natural resources by conserving them and uses of technology to possibly find new ones" (Author 2, 2000, p. 143).

2. "Liz is a very colorful and vibrant person, always smiling and happy. Liz plans on attending college on a softball scholarship and pursuing a law degree" (Author 2, 2000, p. 144). (a) Assessment grade: A.

- *Sally*

1. "I think of the natural world as what God gave us to take care of. The natural world is somewhat knowable through science and religion. It is too big to be entirely explained. For example, how can you be sure that an animal is truly extinct if you can't explore all areas of the world. Science and scientists help us to know some of the natural world because things can be predicted. The predictableness allows us to answer how things work, but we will never really know why things work. Some things are unpredictable like hurricanes, tornadoes, and volcanoes. Science can teach us how to be better conservationists through research and technology so we can avoid pollution" (Author 2, 2000, p. 141).
2. "For Sally, religious knowledge set an upper boundary on scientific knowledge. She is a very serious and sober person who knows the value of an education. She plans on attending college and pursuing a career in marine biology, child psychology, or public relations." (Author 2, 2000, p. 141). Assessment grade: A.

- *Samantha*

1. "Nature is inspirational. Words like beautiful, powerful, pure and peaceful come to my mind. When I think about nature, I also think about God. These are my first thoughts when you say the word "nature." Because Nature comes from God, we have an obligation to take care of it. Our Earth is in trouble. Nature can be understood although it is very complex and sometimes difficult to understand. There is an order to part of nature. Things like food webs or plant life cycles can be understood and protected" (Author 2, 2000, pp. 132-133).
2. "Samantha is a quiet, shy and thoughtful girl who works hard in school for the grades that she earns. She plans to go first to community college after her high school graduation and then continue for two years at a state university. She wants to pursue a profession in mass communications or journalism. Although Samantha has not been very successful in the science classes that she has taken, she likes science and is very much concerned about environmental issues" (Author 2, 2000, p. 133). Assessment grade: not reported.

E. Science-Avoidance

"I avoid thinking about science in or out of school, as much as I can get away with ignoring it."

- *Allen*

1. "Nature is knowable to some extent; like people can recycle and fix the ozone layer by not driving cars and stuff. But most of [Nature] is not knowable" (Author 2, 2000, p. 142).
2. "Allen was one of 3 students not to mention science; nor did he speak of any order in Nature…. He only functions while in school and really does not have the self-discipline to do homework or study for tests at home. He would really like to race dirt bikes professionally" (Author 2, 2000, p. 142). Assessment grade: C.

- Holley

1. "Nature is just there, very big and complex, which makes it somewhat confusing. I do not recycle because nature is probably not in danger now or during my lifetime, so what's the point" (Author 2, 2000, p. 142)?
2. "Holley is a reluctant participant: to give any information, to discuss her own thoughts and ideas. Refuses to participate in class discussions. Dresses in a rebellious fashion and enjoys provoking reactions from others" (Author 2, 2000, p. 143). Assessment grade: C.

- *Jackie*

1. "Nature is alive. It is everything around us like plants and animals. It does not include far off planets. Everyone exploits the natural world. Nature is very mysterious, which makes it very confusing and unpredictable. I don't mean to say that it is totally mysterious. There are some things that can be knowable, like medical science. … Knowledge of the natural world also gives us the information needed to restore our world. We get some of this knowledge by taking science classes and through the media, like the discovery channel. The natural world is is everything that God created and therefore has a purpose" (Author 2, 2000, p. 139).
2. "Most of the students in this study [like Jackie] had much less to say about science in regard to Nature. [No science content related to school science was mentioned.] She plans on going to college or to enlist in the military to eventually become a police officer or a physical therapist" (Author 2, 2000, p. 139). Assessment grade: not reported.

- *Paula*

1. "God created the natural world, which makes it very mysterious and, for the most part, unexplainable. Man has "doomed" the planet. I don't understand the human world and why people feel the need to study Nature. Studying Nature only causes trouble. It is a very spiritual world if man's technology would not interfere with it" (Author 2 et al., 1999, p. 551).
2. "When attending her classes, she is an intelligent and creative person making good grades and participating in class discussion with vibrancy. She is not self-disciplined when it comes to her studies, however. She seems to be a very progressive, spiritual person. Unfortunately, she dropped out of school at 14 years old" (Author 2, 2000, pp. 137-138). Assessment grade: not reported.

- *Simon*

1. "Some aspects of Nature are knowable and it is important that we learn more about it. What we learn comes from both school and personal experience. Our lack of understanding Nature has caused us to exploit our natural resources. Possibly we are doomed. You could say I'm in touch with nature. Though I understand only a little about it, I like the mystery of not understanding everything. I also have some religious

feelings about nature. I do think that some God created the Earth" (Author 2, 2000, p. 128-129).

2. "We can easily imagine… Simon wanting to know what science has to do with the meaning, purpose, beauty, and mystery of Nature" (Author 2 et al., 1999, p. 559). "Simon is a puzzle to his teachers. Although he tests quite well on achievement tests, he is very unsuccessful in school. He has great difficulty organizing his thoughts both orally and in writing. Simon is interested in the subjects discussed in his science classes. He will ask questions after class although rarely in class. He intends to pursue a profession in the military, become a police officer or 'work as a manager for my brother.' He has taken three classes in high school with limited success. He clearly states that he does not like to study" (Author 2, 2000, p. 129). Assessment grade: not reported.

F. *Science-Resistant*

"I generally distrust science; or I get terribly anxious or sometimes even ill over learning science, especially when preparing for, and writing tests."

- *Art*

1. "Man has changed the natural world today by exploiting its resources and polluting the environment. I am lost. Hopelessness creeps around every corner. The past can't be accepted. Lies follow my conscience when a school. Participation is this bureaucracy disgusts me in every way." (Author 2, 2,000, pp. 131-132).
2. "Art was much more impressed with the knowledge of nature one achieves by personal experiences with nature and Native American knowledge. We found Art to be both thoughtful and articulate. Art was much opposed to science as Howard was supportive." (Author 2 et al., 1999, p. 549). His immediate goal is to dop out of high school and attend community college (Author 2, 2000, p. 132). Assessment grade: not reported.

APPENDIX B

Continuum of Science Identity Strengths: Criteria Revealed During Categorizing

Section A below provides general criteria for teachers to draw upon when constructing their own specific criteria. Section B below serves as an *initial* list of criteria that were produced by the authors when categorizing a diverse set of 16 ninth-grade students. When teachers use the continuum, they are invited to begin with selections from the authors' list, and then introspect on the implicit criteria they actually used when categorizing their own students. There will certainly be diversity from class to class. Proficiency grades based on quizzes and tests are purposefully missing from the criteria due to some students playing Fatima's Rules, described in the article (subsection "Playing Fatima's Rules").

A. In General

The greater degree to which a student identifies with science's cultural features, the stronger the student's science identity becomes. This occurs in at least three general dimensions: *what they believe, what they value, and who they want to become*.

In other words, "the acquisition of discourses of *thinking, acting, valuing, interacting, feeling that makes you a particular kind of person* (Brickhouse, 2007, p. 90, emphasis added).

B. Less General and Will Be Modified by a Teacher for Personal Use

Science-oriented

- Explicitly indicates wanting to be a scientist, engineer, or a closely related profession that requires a university, college, or polytechnic degree.
- Does or talks science outside of school.
- Spontaneously gives evidence of knowing scientific knowledge in depth.
- Shows some awareness of the nature and history of science.
- Indicates a strong "separated" value cluster: valorises rules, abstraction, objectification, impersonality, unfeelingness, dispassionate reason and analysis, and tends to be atomistic and thing-centred in focus (Gilligan, 1982).
- May have other interests in addition to their fascinated interest in science.
- Enjoys being recognized as a science person.

Science-curious

- Preparing for a science-related profession is not a necessity.
- Does or talks science outside of school.
- Explicitly notes the value of scientific knowledge for outside of school.
- Spontaneously gives evidence of knowing the scientific knowledge that causes curiosity.
- Recognizes there are unknowns for scientists to explore or clarify.
- Has other interests in addition to science, which may compete with their science interest.
- Expresses a degree of a "separated" value cluster (defined just above).

Science-interested

- Enjoys school science, but not necessarily its academic side.
- Implicitly, if not explicitly, indicates that science can be interesting, but has no plans for becoming a scientist or engineer (or requiring a university degree for any related occupation).
- Interested in a science-related job that does not require a university or polytechnic degree.
- Science is one of many consuming interests, some of which are more important than science.
- Indicates having some scientific knowledge.
- Normally does not express pejorative ideas about science, other than legitimate critical analysis.

Science-disinterested

- Science is not in their world, but is a notable school requirement.
- Implies that science can produce valuable knowledge, but embraces some pseudo-scientific ideas.
- Can see something positive about science's role in society, in spite of their disinterest.
- Implies that other interests are more important than science interests.

Can get high marks in science by playing Fatima's Rules (i.e., being a good memorizer and/or teacher manipulator).
- Interested perhaps in social service types of employment.
- Evidence of minimal scientific knowledge.

Science-avoidance
- Uses tactics to avoid school science (e.g., homework often not complete).
- Normally, does not mention specific scientific knowledge except for medical science.
- Unconcerned with low marks, as long as the student passes the course.
- Can speak generally about the importance of knowledge, but not scientific knowledge.
- Little understanding of how science works, due mostly to forgetting what was memorized.
- Expressing concern about potentially damaging knowledge, implicitly linked to science.
- Finds excuses for not attending class, especially on days that a test is taken.
- Other interests are definitely more important than an interest in science.
- Indicates a fairly strong "connected" value cluster: valorises relationships, connections, empathy, caring, feelings and intuition, and tends to be holistic and human-centred in their concerns (Gilligan, 1982).
- Employment interests have nothing to do with needing post secondary studies in science.

Science-resistant
- Expresses degrees of hostility toward science (e.g., blaming it for the poor state of the world) although some positive comments are made about science and scientists.
- Expresses a negative reaction to being tested.
- Explicitly prefers other forms of knowledge to scientific knowledge.
- Indicates a strong "connected" value cluster (defined just above).
- Employment interests have nothing to do with needing post secondary studies in science.
- Has serious interests outside of school, but nothing related to science.

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